

Baryon Number Flow in High-Energy Collisions

Gerald T. Garvey

Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Boris Z. Kopeliovich¹ and Bogdan Povh

Max-Planck Institut für Kernphysik, Postfach 103980, 69029 Heidelberg, Germany

Abstract

It is not obvious which partons in the proton carry its baryon number (BN). We present arguments that BN is associated with a specific topology of gluonic fields, rather than with the valence quarks. The BN distribution is easily confused with the difference between the quark and antiquark distributions. We argue, however, that they have quite different x -dependences. The distribution of BN asymmetry distribution is nearly constant at small x while $q(x) - \bar{q}(x) \propto \sqrt{x}$. This constancy of BN produces energy independence of the $\bar{p}p$ annihilation cross section at high energies. Recent measurement of the baryon asymmetry at small x at HERA confirms this expectation. The BN asymmetry measured at mid-rapidities in heavy ion collisions is substantially enhanced by multiple interactions, as has been observed in recent experiments at the SPS. We expect nearly the same BN stopping in higher energy collisions at RHIC.

¹On leave from Joint Institute for Nuclear Research, Dubna, 141980 Moscow Region, Russia

1 Introduction

It is not obvious what carries the baryon number (BN) in a proton. It is clear that the BN of a hadronic system is given by the number of quarks minus the number of antiquarks divided by three, and that this number is conserved in a closed system. This definition, naively applied readily leads to an association of BN with valence quarks. Recall that the density of valence quarks in a baryon of flavor i , carrying a momentum fraction x is defined as $q_i^v(x) = q_i(x) - \bar{q}_i(x)$,

$$\sum_i \int_0^1 dx [q_i(x) - \bar{q}_i(x)] = \sum_i \int_0^1 dx q_i^v(x) = 3 \quad (1)$$

which motivates the misconception that the the valence quarks carry the the BN. This is certainly is not correct. If one considers the reaction

$$\pi^- + p \rightarrow \Omega^- + K^+ + 2 K^0, \quad (2)$$

it is clear that BN is conserved, but none of the valence quarks in the initial proton appear as valence quarks in the Ω^- . This example holds a clue. The gluon fields create three s and three \bar{s} quarks. It seems that no baryon number has been produced but the $3\bar{s}$ couple with $2d$ and a u to form mesons and $3s$ quarks form the Ω^- . Thus BN must be carried by some other partons in the proton, probably gluons.

Another example which creates doubt that valence quarks carry BN is the central collision of two heavy ions at very high energies (RHIC, LHC). Naively, in such high energy collisions one expects to find near zero net baryon number at mid-rapidities. This is because the valence quarks of the colliding nuclei are difficult to stop, indeed energy loss of a quark propagating through nuclear medium is known to be rather small, $\Delta E \sim 10 \text{ GeV}$, and energy independent [1] - [3]. If the valence quarks are the carriers of baryon number they will sweep the baryon number along to large positive and negative rapidities. We believe that the picture is true for the valence quarks but not for BN. The final state emerging from such a collision is shown schematically in Fig. 1. A substantial fraction of the initial

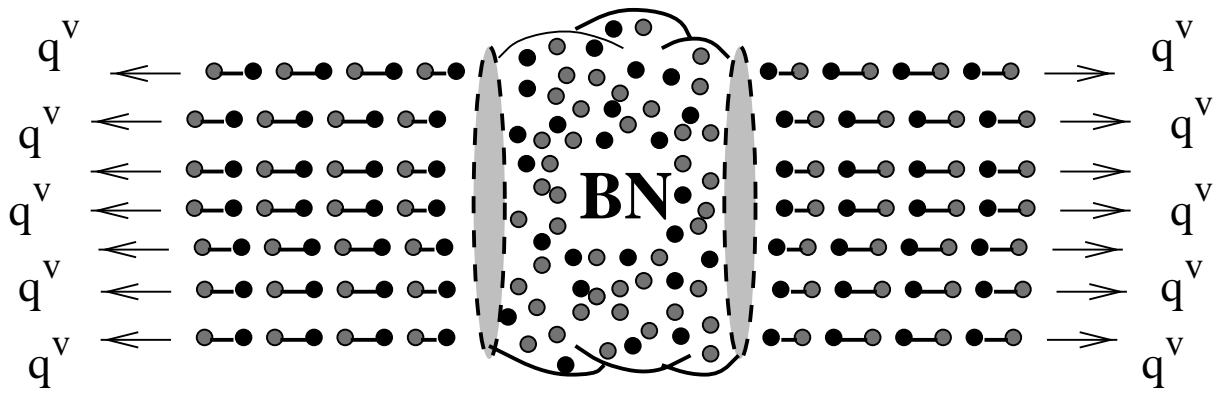


Figure 1: A cartoon illustrating the final state following central collision of (Lorentz contracted) relativistic heavy ions. Grey and black circles correspond to quarks and antiquarks respectively. The valence quarks q^v escaping the collision region produce jets consisted mainly of mesons. The major fraction of BN of the projectile nuclei stops at mid rapidities.

energy of the nuclei is stored in the valence quarks. The rest of the energy is carried by many softer gluons and quark, anti-quark pairs. A high-energy quark cannot be stopped by the soft interactions it encounters in passing through a heavy nucleus. The valence quarks pass through the collision region losing only a small fraction of their initial energy via gluon radiation induced by multiple soft collisions. Many softer $\bar{q}q$ pairs and gluons are left behind as shown in Fig. 1. The energy density created by these soft partons that are left behind is believed to be sufficiently high, that a quark gluon plasma is created.

On the other hand, after propagation through a heavy nucleus the initial valence quarks completely lose their identity as a constituent of a nucleon. Therefore, these quarks independently emerge from the collision and produce fragmentation jets correlated with the colliding beam direction. The jets will consist mostly of mesons and a small number of baryon-antibaryon pairs. Therefore the BN carried by the colliding nuclei is not to be found in the beam fragmentation regions but is stuck in the glue near mid-rapidity.

Assuming that the above illustrations are correct, a few conclusions immediately follow.

- (i) The valence quarks readily survive this collision and remain in the fragmentation regions of the projectile nuclei, while the BN does not. Therefore valence quarks are not the carriers of BN.
- (ii) BN stopping of does not necessarily correspond to energy stopping. The energy carried by the valence quarks may penetrate through the nuclei but the BN does not. Of course if with a vanishing probability the energy is completely stopped then the BN is also stopped.
- (iii) Because the BN is stopped along with the glue, it appears that the gluon field may carry the BN.

The latter conjecture has been around for quite some time. Some 25 years ago the concept of a gluonic string junction as the carrier of BN was proposed [4, 5]. Interest in this subject has waited over intervening two decades and has only intermittently been discussed (for the latest review see [6]) The early papers referred to above were written in the context of dual topological theories, Regge theory, and first generation QCD models. Current readers have little familiarity with these topics so these earlier presentations are difficult to follow or evaluate. The topic however has enjoyed renewed interest because of experimental results from HERA, which we will discuss later, and the recognition of its relevance to critical aspects of relativistic heavy ion collisions. In this latter instance, it is widely held that because the valence partons of the nucleons readily pass through the severely Lorentz contracted collision volume that they would emerge carrying most of the BN. This description would create a very hot region of strongly interacting matter containing small BN. However, in the heavy ion collisions observed at the CERN SPS there are a far greater number of baryons at mid-rapidity than expected assuming that BN is associated with valence quarks. Not only that, but a surprising number of these baryons contain strange valence quarks. In what follows we do not present new physics, but only attempt to make more accessible the idea that BN is not tied to valence quarks, to show how BN slides back to mid rapidity, and to show where experimental results bear out these ideas.

2 Probes for the BN distribution

To experimentally investigate the questions surrounding the nature of BN one needs to identify suitable probes and reactions. Inclusive deep-inelastic scattering is clearly not useful as it probes only the distribution of electric charge and is insensitive to either gluons or BN. Not surprisingly, the earliest probe used to investigate BN was the $\bar{p}p$ reaction where the annihilation cross was measured. Another and more satisfactory way to study the x distribution of BN is to measure the BN asymmetry of produced particles. We will employ the usual assumption that there is a strong correlation in rapidity between the initial partons and the BN of the hadrons they produce.

2.1 BN annihilation does not vanish at high energies

Experiments on BN annihilation via $\bar{p}p \rightarrow \text{mesons}$ were carried out in the 1970s. These results have been under intensive discussion for many years. We summarize some of the important observations and conclusions. If BN is associated with gluons, an immediate consequence is that BN should occur over the entire rapidity scale because of the fact that gluons are vector particles. No example or physical reason leads us to believe that non-perturbative effects would alter this consequence. In section 3 we will illustrate how the process works. For the present, it is useful to recall the behavior of a couple of processes that are mediated by gluon exchange. For example, all hadronic total cross sections are observed to nearly energy independent, and further there is a persistence of large rapidity gaps observed in diffractive processes (Pomeron exchange) at the Tevatron and HERA. These are just 2 examples of the evidence for the persistence of gluonic interactions over all rapidities.

Therefore, if we associate BN with gluonic configurations, it is natural to expect that it will be rather uniformly distributed in rapidity and that the $\bar{p}p$ annihilation cross section will not vanish at high energy.

The first claim that the $\bar{p}p$ annihilation cross section is energy independent at high energies was made by Gotsman and Nussinov [7]. They employed a string junction model proposed earlier by Rossi and Veneziano, and suggested that annihilation results from the overlap of a gluonic string junction and a string anti-junction followed by rearrangement of the gluonic strings as is illustrated in Fig. 2 on the bottom. They made a natural

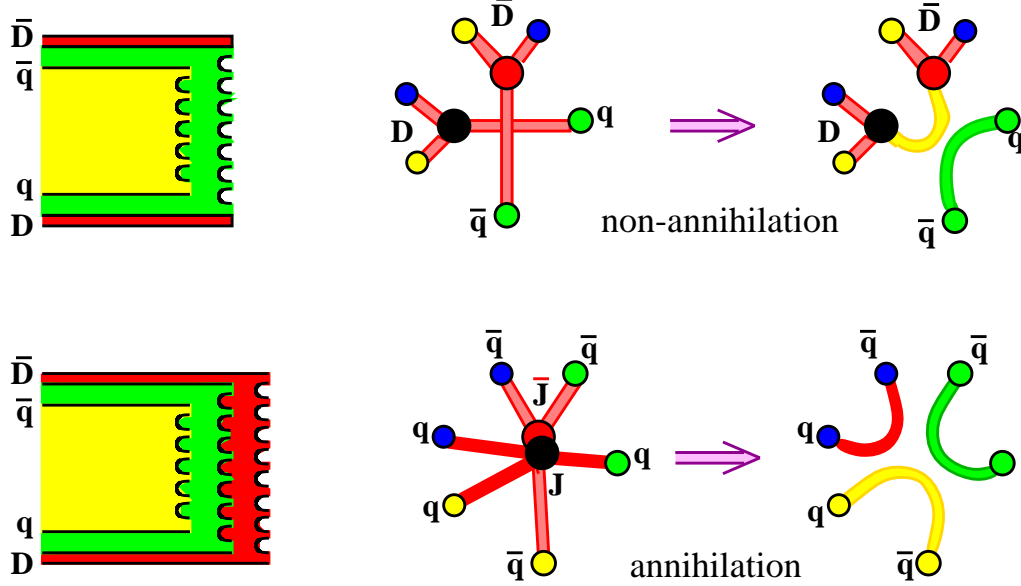


Figure 2: The cartoon shows interaction of a proton consisted of a diquark (D) and a quark with an antiproton. Crossing of the strings in impact parameter plane leads to non-annihilation final state with two strings (two sheet topology [5]). Annihilation corresponds to overlap of J and \bar{J} leading to three string production.

assumption that this process is energy independent in analogy to nonannihilation collisions corresponding to crossing of the strings as shown in Fig. 2 at the top. The asymptotic annihilation cross section was estimated by assuming that the string junction has a size of the order of the transverse dimension of the strings, $\sim 0.2 - 0.3 \text{ fm}$. With this assumption they found $\sigma_{ann}^{\bar{p}p} \approx 1 - 2 \text{ mb}$.

A confirmation of this pictorial description comes from a perturbative QCD treatment of

annihilation suggested in [8, 9]. Annihilation in the $\bar{p}p$ interaction arises from multigluonic exchange in a color-decuplet state as shown in Fig. 3. As already mentioned, the cross

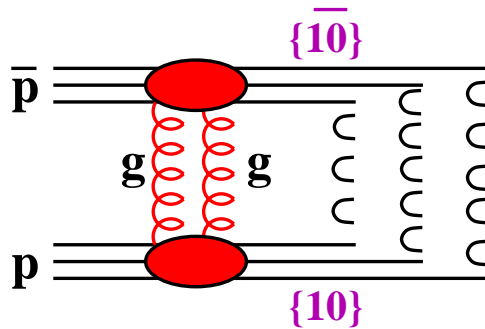


Figure 3: *Perturbative graph for $\bar{p}p$ interaction via two gluon exchange in decuplet color state. The three string final state leading to annihilation is also shown.*

section is energy independent since the gluon is a vector particle.

The value of $\sigma_{ann}^{\bar{p}p} \approx 1 - 2 mb$ predicted from a perturbative evaluation [9] of this annihilation cross section $\sigma^{\bar{p}p}$ is the same as that obtained by Gotsman and Nussinov using the nonperturbative string junction approach.

Another, strong confirmation of this approach and the energy independence of $\sigma_{ann}^{\bar{p}p}$ comes from the analysis of the difference between the multiplicity distributions in $\bar{p}p$ and pp . The difference in multiplicity is due to the specific three-string topology of the events with string junction exchange [5]. They have a multiplicity 1.5 times the non-annihilation events as one can see from Fig. 3. Using the enhanced multiplicity of the asymptotic purely gluonic annihilation process, the asymptotic and asymptotic annihilation processes has been separated. The result of the analysis, [9] $\sigma_{ann}^{\bar{p}p} \approx 1.5 \pm 0.1 mb$ agrees very well with theoretical expectations. The data used in the analysis included lab energies ranging from 10 to 1480 GeV, and beautifully confirm the energy independence of this mechanism. Thus we have shown using theoretical analysis of experimental data that the purely asymptotic mechanism of BN transport over large rapidity intervals is rapidity independent. This means

that the BN distribution function at small x is proportional to $1/x$, similar to sea quarks and gluons.

2.2 BN asymmetry of produced particles

Another probe of the BN distribution is the BN asymmetry of produced particles which we define as

$$A_{BN}(x) = 2 \frac{N_{BN} - N_{\overline{BN}}}{N_{BN} + N_{\overline{BN}}} . \quad (3)$$

Here $N_{BN(\overline{BN})}$ is the density of produced BN (anti-BN) which is a function of Bjorken x . We consider a case with initial $BN = 1$ (proton - meson (photon) collisions).

The BN asymmetry (3) can be interpreted as a ratio of production rate of stopped BN and BN created from vacuum (this is why we have factor 2 in (3)). This is correct only if $A_{BN}(x) \ll 1$, *i.e.* if the effect of stopping is relatively small.

It is natural to assume that the BN asymmetry of produced particles arises from the BN asymmetry of the parton distribution in the projectile proton. Then, the observation of an excess of BN produced at a rapidity far below that of the projectile proton can be treated as a measure of the BN at small x ($< 10^{-3}$) in the partonic distribution of the proton.

As the energy dependence of the annihilation cross section is known one can readily predict the expected BN asymmetry. Let us treat the case of a meson-nucleon collision viewed from the rest frame of the nucleon. The incident high energy meson develops a parton cloud containing fluctuations of baryon-antibaryon pairs ($J - \bar{J}$) with low probability. Of course, this parton cloud is locally BN symmetric. However, the antibaryon fluctuation in the meson can annihilate with the BN of the target nucleon, as is illustrated in Fig. 4, so that the partonic fluctuation of the meson now has BN. The resulting BN asymmetry is given by [10],

$$A_{BN}(x) = \frac{\sigma_{ann}(s = m_N^2/x)}{\sigma_{in}^{MN}} , \quad (4)$$

where σ_{in}^{MN} is the inelastic meson-nucleon cross section. Using the asymptotic value of

n of produced particles. Indeed, the stopping of a string junction requires a three string configuration which produces a higher multiplicity of final particles than a two string configuration, corresponding to the case when the string junction is accompanied by a valence quark. The baryon symmetric contribution dominating the denominator in baryon asymmetry definition Eq. (3) is related via unitarity to the Pomeron which also corresponds to two-string in the final state. This difference between the two mechanisms in multiplicity distribution is illustrated in Fig. 5. As a result, the relative contribution of the asymptotic,

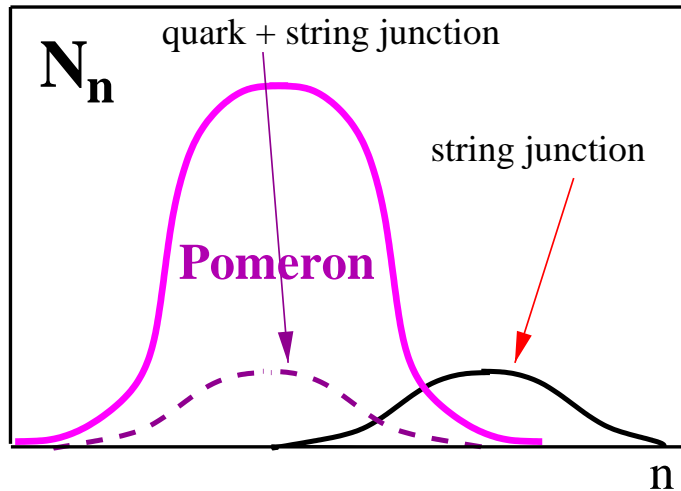


Figure 5: *Multiplicity distribution for produced pions corresponding to the baryon symmetric contribution (Pomeron) dominating the denominator in (3) and baryon asymmetric mechanisms related to quark-junction and single junction transfer contributing into the numerator in (3).*

gluonic mechanism of BN transfer increases as function of multiplicity. The results of the analysis performed in [13] for dependence of baryon asymmetry on multiplicity of produced particles are compared with data from the H1 experiment [11] in Fig. 6. Apparently, the preasymptotic quark-exchange mechanism is excluded, while the gluonic mechanism is in a good accord to the data.

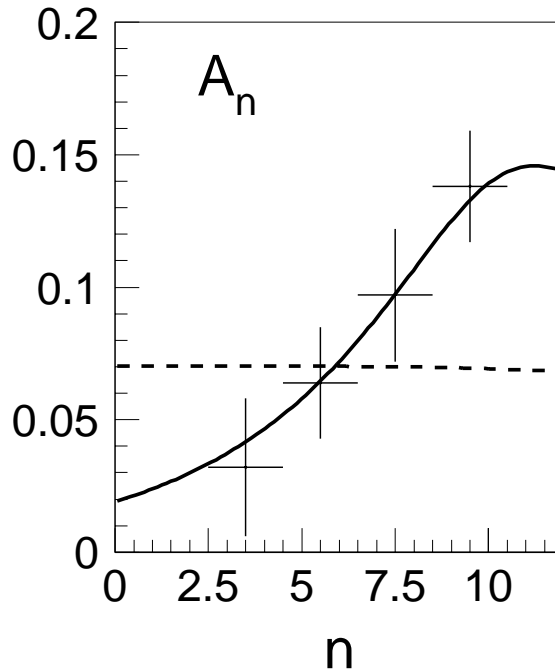


Figure 6: *Dependence of baryon asymmetry (3) on multiplicity of produced particles. Solid and dashed curves show results of calculations of [13] assuming pure gluonic or preasymptotic quark exchange mechanisms respectively. Data are from [11].*

This result from the H1 experiment at HERA is the first experimental evidence for a large BN asymmetry in the proton sea at small x . Similar measurements can be performed with virtual photons, but we expect no significant dependence on Q^2 .

2.3 Hyperon production

It is also possible to measure BN stopping via production of hyperons which are sometimes easier identified. It may help to discriminate between the two mechanisms, asymptotic and preasymptotic. If BN flows via the gluonic mechanism the string junction picks up only sea quarks to create the final baryon. This leads to enhancement of hyperon production with relative statistical weights $8/27$, $4/9$, $2/9$ and $1/27$ for nonstrange baryons, Λ or Σ , Ξ and

Ω respectively. It would be different, $4/9$, $4/9$, $1/9$ and 0 , respectively, if the mechanism is preasymptotic one, associated with one of the valence quarks. On top of that there is of course a dynamical suppression factor w^n , where n is the number of strange quarks in the baryon, and $w \sim 1/3$ is relative production probability of a strange quark from vacuum.

The first measurements by the H1 Collaboration [14] of BN asymmetry for Λ hyperons resulted in $A_\Lambda < 0$ compatible with zero. Precise measurements of baryon asymmetry for hyperons (Λ^0 , Ξ , Ω , Λ_c) were performed recently by the E791 Collaboration in collisions of 500 GeV negative pions with carbon nuclei [15]. There are a few comments concerning these data which follow in order.

- The c.m. energy in this experiment is twice as low as the maximal energy reached in pp collisions at ISR in the experiments studying the p/\bar{p} asymmetry at mid rapidity [16] and rapidity dependence of this asymmetry [17]. According to calculations in [12] the observed asymmetry in both experiments is dominated by the preasymptotic mechanism of valence quark and string junction exchange, and this is also true for the E791 data.
- The definition of asymmetry used in [15] is different from our (3), it does not include factor 2. Therefore all measured asymmetries should be doubled to compare with our predictions and with the data from ref. [11].
- The nuclear target can modify BN asymmetry at negative x_F .
- The data demonstrate a rising dependence of asymmetry on transverse momentum. This is not surprising since both preasymptotic and asymptotic mechanism involve breaking of the projectile diquark in the nucleon. There are many experimental and theoretical evidences [18] that the nucleon wave function is dominated by a component with a compact diquark with separation $\sim 0.3\text{ fm}$. In this case diquark destruction leads to liberation of rather large intrinsic transverse momenta of the quarks.

According to the partonic interpretation in Section 2.2 illustrated in Fig. 4 the probability of BN flow (the numerator in (3)) is proportional to the number of BN , \overline{BN} pairs created from vacuum. The latter is the denominator in (3) provided that $A_{BN} \ll 1$. In this case the number of sea BN , \overline{BN} pairs cancels and the BN asymmetry can be treated as a measure of BN stopping.

At this point we should distinguish between the BN asymmetry $A_{BN}(x)$ and the asymmetry

$$A_B(x) = 2 \frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}} \quad (5)$$

for a particular species of baryon, B . The produced BN (string junction) is realized via production of a variety of baryons with corresponding relative branchings. Since the mechanisms of hyperon creation from vacuum (the denominator in $A_B(x)$) and via the stopped string junction (the numerator in $A_B(x)$) may be quite different, the baryon asymmetries for hyperons ($B=H$) will differ from the BN asymmetry (3). For instance, if the contribution of BN flow to production of a hyperon is substantially greater the one from vacuum, a specific baryon asymmetry (5) will approach the maximal value 2, while the BN asymmetry (3) may be small. This may happen with multi-strange hyperons if the gluonic mechanism dominates. Indeed, production of multi-strange hyperons from vacuum should be greatly suppressed by the string mechanism for BN production suggested in [1]. In this case $A_B(x)$ is not a characteristic of BN flow.

Calculation of baryon asymmetry for hyperons is more difficult problem than for BN asymmetry (3) especially at medium high energies. It requires decomposition into specific baryons of the BN produced from vacuum. A better characterization of BN flow would be ratios of $N_B - N_{\bar{B}}$ for different baryon species normalized by the same yield of vacuum pairs, *e.g.* $N_p + N_{\bar{p}}$.

3 How BN Flows

We shall now illustrate how BN can range over a very large interval in x , and in particular how it can appear at very small x .

The string configurations of the color fields in a meson and in a baryon are quite different. A meson looks like a $\bar{q}q$ pair connected by a color flux tube [1]. The configuration of strings in a baryon having minimal energy has a form of the Mercedes-Benz star (see Fig. 2), and the point where the strings join is called string junction (J) [4]. This configuration of gluonic fields also follows from the gauge invariant form of the operator with $BN = 1$ as suggested in [5]. Correspondingly, an anti-string-junction may also be introduced (\bar{J}) as the source of antibaryons. J and \bar{J} can interact and annihilate to mesons.

The association of BN with the topology of gluonic fields rather than with quarks is not new. A topological view of BN was suggested a long time ago in the chiral soliton model of Skyrme [19]. The Lagrangian of the so called Skyrme Model does not even contain quark degrees of freedom.

An assignment of BN to a string junction is quite compatible with the results presented in Section 2 which showed that BN displayed characteristics normally associated with gluons. Of course a gluon does not have any BN, and the dynamical association of BN with gluonic fields is explained in following paragraphs.

In the infinite momentum frame the string junction shares the proton momentum, therefore, it can be given a partonic interpretation. Since a Fock state decomposition of the proton contains components with a few sea $\bar{q}q$ pairs,

$$|p\rangle = |3q^v\rangle + |3q^v q^s \bar{q}^s\rangle + |3q^v 2q^s 2\bar{q}^s\rangle + \dots , \quad (6)$$

three sea quarks can form a baryon by extending the processes illustrated in Fig. 7. Thus it is conceivable that BN might have a distribution $\propto 1/x$ at small x similar to that of gluons and sea quarks [10].

Though at first glance it appears simple, it is not trivial to push the BN in a baryon

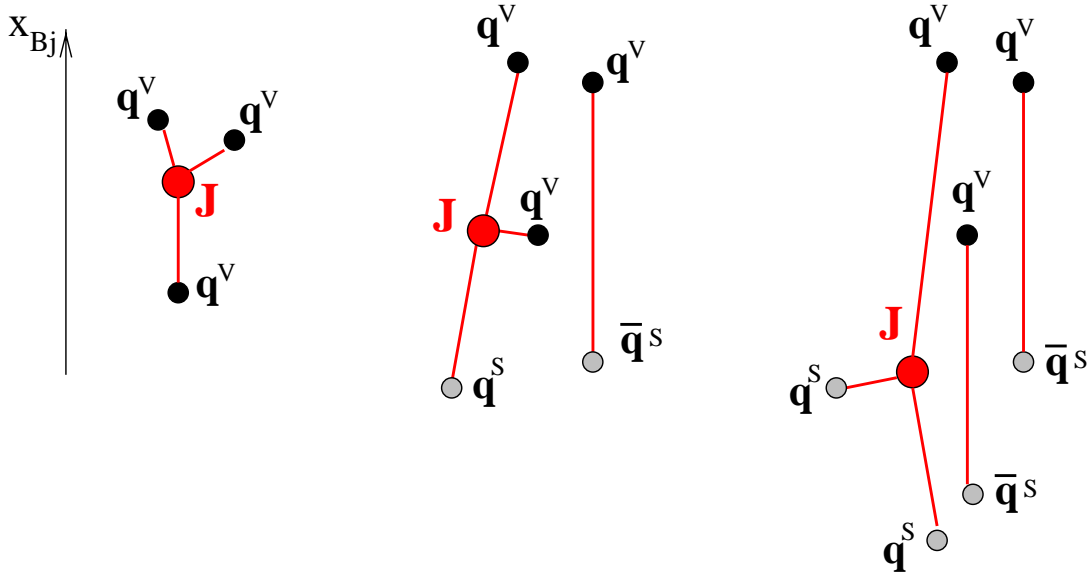


Figure 7: *String configurations corresponding to different terms in Fock state decomposition (6). Grey and black circles show the sea and valence quarks respectively. The dotted lines show the color strings. Conventionally we assume that the vertical axis corresponds to Bjorken x .*

like the proton down to small x . One can imagine the parton cloud of a valence quark as a chain of $\bar{q}q$ pairs as shown in Fig. 8a. The terminus of this chain is, of course, a quark with $BN=1/3$. In the proton this valence quark is accompanied by a valence diquark. The valence diquark has a color wave function $\{\bar{3}\}$, the same as a \bar{q} in order that the proton's valence wave function $u(ud)$ be an over all color singlet. The valence diquark therefore develops a $\bar{q}q$ chain that terminates in a \bar{q} . Thus the net $BN=0$ at small x as shown in Fig. 8b. Only if the three valence quarks get into a decuplet color state can they propagate $BN=1$ down to small x (Fig. 8c). The decuplet state can be created in higher Fock components of the proton such as, say $uudg\bar{q}q$ where the color degrees of freedom of the $\bar{q}qg$ allow the uud valence configuration to be a decuplet. In this instance the three $\bar{q}q$ chains can transport $BN=1$ to small x . The probability to produce a color decuplet $3q$ state in hadronic collisions turns out to be quite small, as evaluated in ref. [9].

A few remarks are in order. It is clear that the $\bar{q}q$ chain while carrying the baryon number

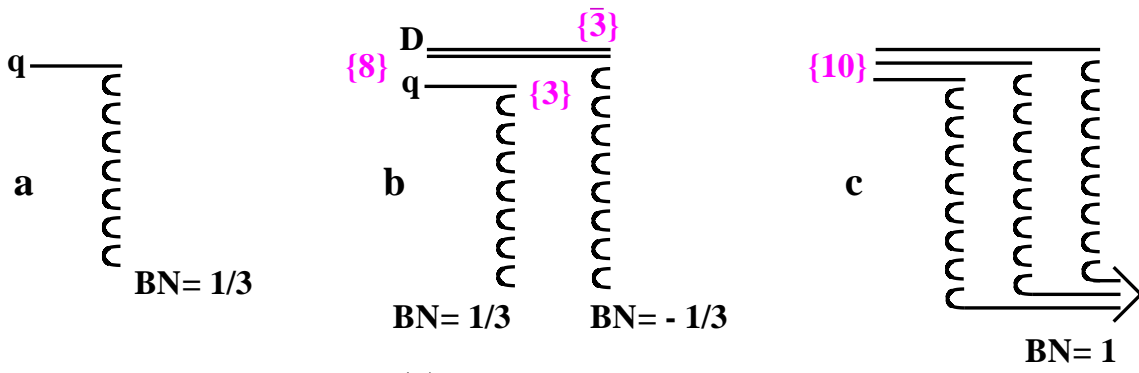


Figure 8: The $\bar{q}q$ chain (a) effectively transports the BN of the valence quark down to small x (Bjorken x is assumed to follow the vertical axis). If, however, the valence quark and diquark form a color octet in final state (b), no BN is transferred to small x region. Nevertheless if the valence quarks are in color decuplet state (c) the BN is transported by three $\bar{q}q$ chains.

of its origin does not have to carry its flavor. Thus the baryon generated at low x need bear no resemblance to the the valence baryon, for example $uud \rightarrow sss$ as we discussed earlier. It is quite clear that in a real sense the $\bar{q}q$ chain carries the baryon number of its origin. Thus the idea that the junction of three such chains is the topological realization of BN seems quite reasonable and does not contradict any known fact. Of course the mechanism discussed above is not the only way in which BN moves to lower x . Returning to Fig. 8, usually BN emerges from a collision carried by the valence diquark which picks up another quark from the vacuum. Such a process would have the resulting BN at relatively large x ($x > 0.1$). On the other hand if two of the quarks are from the sea then the x of the BN is brought much lower. This can be interpreted as a purely gluonic transfer, of just the junction, and only then does it become independent of x . As this mechanism is much smaller than the two previously mentioned, it can only be clearly observed at very low x ($x < 10^{-3}$) where the diquark- and preasymptotic quark-exchange mechanisms have disappeared.

4 Heavy ion collisions

The pedagogical example of central collisions of relativistic heavy ions mentioned in the introduction is in fact more pertinent than simply as an illustration. It shows that at high energies the momentum of the projectile valence quarks survive the multiple interactions in the collision, but lose their identity as baryonic constituents. This means that BN of the projectile nuclei moves from the projectile fragmentation regions and accumulates at central rapidities. This BN flow moderated by external gluons [12] should lead to a considerable baryon stopping at mid-rapidities.

The BN observed so far in proton-proton collisions at SPS and ISR remains primarily in the nucleon's fragmentation regions and is only found at smaller rapidities because of the spread in the momentum fractions of the valence quarks [12] as is sketched in Fig. 9. A

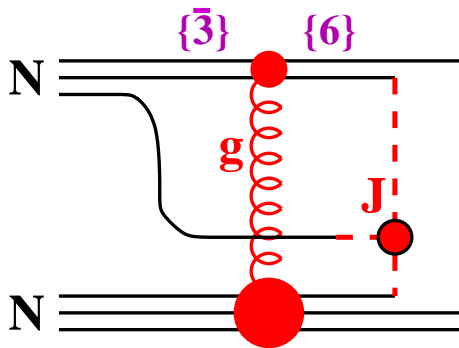


Figure 9: *Interaction of a fluctuation of the incident proton containing a valence quark and the string junction at small x (with a small probability $\propto \sqrt{x}$) Interaction is illustrated using a perturbative gluonic exchange for the sake of simplicity.*

fluctuation of the incident nucleon into a fast diquark and relatively slow quark interacts with the target (gluon exchange is used for illustration). As a result the longitudinal momenta of the valence quarks remain unchanged, but the diquark may switch from anti-triplet to

sextet color state. In this case the projectile BN acquires the rapidity of the slow valence quark. The cross section dependence on the rapidity interval $\propto \exp(-\Delta y/2)$ follows the primary momentum distribution of the valence quark. The perturbative estimate of the absolute value of the distribution performed in [12] is in a good agreement with data. The same mechanism of diquark breaking applied to $\bar{p}p$ annihilation [20] also explains the data available up to energy $E \sim 10 \text{ GeV}$.

This input was used in [21] to predict that almost all of the BN is stopped in lead-lead collisions at SPS. Why is the stopping so different in the heavy ion case? The probability for the projectile color-anti-triplet diquark to survive multiple interactions vanishes in a heavy nucleus, therefore the BN escapes from the projectile fragmentation region with a probability close to one. The shift of BN in such heavy ion collisions involves processes really very different from the ones considered in Section 2 as subsequent collisions of the diquark in the nuclear medium are required to reduce the rapidity of the BN. Measurements by the NA49 collaboration [22] confirmed these expectations.

Similar results were recently obtained [23] using a Monte Carlo code that implements the notion of string junctions. In spite of the claim in [23, 24] that the asymptotic pure string-junction mechanism is used, it is only important that they assume a $1/\sqrt{s}$ energy dependence which is the same as ref. [21]. We believe that prescription of value $\alpha_0^J(0) \approx 1/2$ to the Reggeon intercept corresponding to string junction exchange [5] has no justification beyond citation of the result of [25]. In this respect it worth quoting the authors Eylon and Harari: “*the crude model described here, is not meant to be taken seriously as a quantitative description of $\bar{B}B$ precesses.*” [25]. Another assumption of [5] that the asymptotic mechanism of string junction exchange already dominates at energies $E < 10 \text{ GeV}$ and identification of annihilation with the difference between the total $\bar{p}p$ and pp cross sections, contradicts the basic ideas of ref. [25] and was criticized in [6]. Disappearance of the ω exchange in pp scattering would lead to serious troubles for the high-energy phenomenology.

It is assumed in [21] that BN liberated via multiple interactions in heavy ion collisions

move to the rapidities of valence quarks similar to NN collisions as is shown in Fig. 9. If it were true the probability to stop BN at central rapidities would decrease with colliding energy as $s^{-1/4}$, *i.e.* one should expect three times less stopping at RHIC compared to SPS. This is not obvious, however. Indeed, the diquark and quark in the projectile nucleon lose coherence in the very first inelastic interaction on the surface of the nucleus and “do not talk to each other” any longer. The projectile BN associated with the diquark and liberated in subsequent multiple interactions as is shown in Fig. 10a should acquire the rapidity of a valence quark of the target. Even more probable that the BN will be stuck with one of

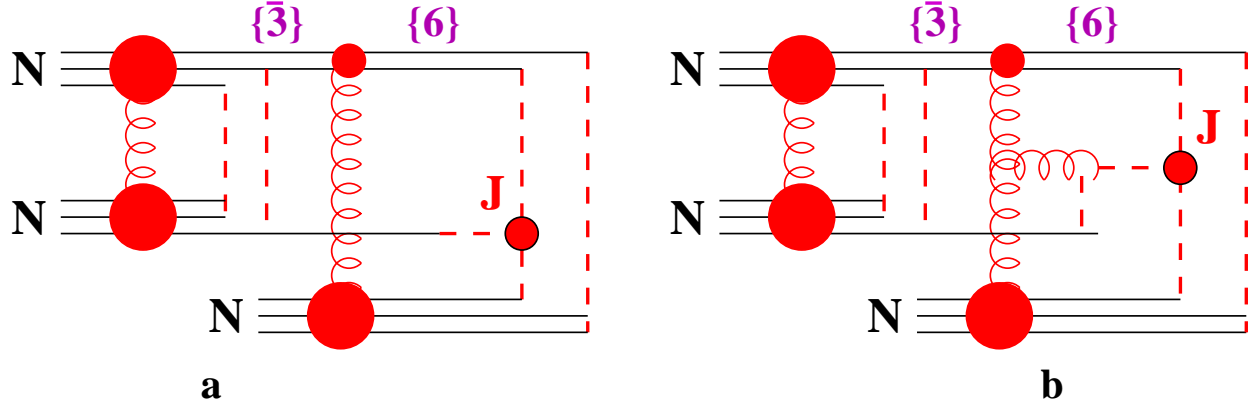


Figure 10: *Double interaction of a nucleon in the target nucleus. The first interaction breaks down coherence between the projectile quark and diquark. The second interaction liberates the projectile BN converting the diquark from the $\{\bar{3}\}$ state to $\{6\}$. The BN acquires the rapidity of a valence quark in the target nucleon (a) or a radiated gluon (b).*

the numerous radiated gluons as is shown in Fig. 10b. The important difference from the preasymptotic mechanism explored in [21] and shown in Fig. 9 is absence of energy dependence in mechanisms illustrated in Fig. 10. Note that this mechanism was also discussed in [21], although, it was assumed that it will take over only at very high energies. However, it follows from the above consideration that on heavy nuclei this double (multiple) step mechanism should dominate at any energy. Thus, we expect nearly a full baryon stopping

in central gold-gold collisions at RHIC as it was observed in lead-lead collisions at SPS. The stopped BN should be spread over the whole rapidity range.

Similar prediction of a rather weak energy dependence for baryon stopping in heavy ion collisions has been proposed recently in [26] basing on the topological treatment for baryon flow. In this approach enhanced BN stopping arises from fusion of abundantly produced Pomeron cylinders into so called membraned cylinders. Although this scheme, similar to [5] suggests a nice geometrical interpretation for BN flow, it is not suitable for numerical calculations and does not lead to any concrete predictions.

It worth mentioning that there is still an exotic possibility that three valence quarks of the projectile nucleon will retain the BN in final state with a substantial probability. Indeed, the three quarks after they have traveled through a heavy nucleus and experienced multiple interactions are completely unpolarized in color space, *i.e.* they are in a color decuplet, octet or singlet state with probabilities $10/27$, $16/27$ and $1/27$ respectively. Thus, with probability $17/27$ they may retain a BN. This does not contradict the previous consideration of multi-step interaction which is supposed to move BN from the projectile to mid rapidities. In the same way multiple interactions can move BN back to the projectile leaving at mid rapidity a baryon-antibaryon pair. In this scenario only fraction $10/27$ of the BN stored in the colliding nuclei can stop. Nevertheless, it seems to be very unrealistic to believe that the three quarks which are hadronizing independently can come together and create a color octet or singlet state. We assume that it never happens, although it should be tested in pA collisions at high energies.

5 Summary, conclusions and outlook

In this note we have rejected the widely spread view that BN should be associated with the valence quarks of a baryon. We also show that BN cannot be identified with the difference $q(x) - \bar{q}(x)$, because BN has a different small x -dependence. That is, the $q - \bar{q}$ difference

vanishes at small x while the BN asymmetry does not. The latter statement is supported by the available data and theoretical arguments of both perturbative and nonperturbative origin. The most convincing being the net gluonic mechanism for BN transfer contributes about 1.5 mb to the difference in the multiplicity distributions in $\bar{p}p$ and pp collisions. Such a rapidity independent cross section is in excellent agreement with the 8% BN asymmetry at $x < 10^{-3}$ and its multiplicity dependence recently measured at HERA.

Consideration of baryon structure in a string model and mechanisms of BN transfer to small x leads to the notion that BN is associated with a specific topological configuration of gluonic fields rather than with quarks. Such a concept is consistent with a similar view underlying the chiral soliton description of baryons [19].

A natural question to address, is what further experimental studies should be done to test, clarify and extend the ideas presented here.

- It is very important to verify the x -independence of the BN asymmetry at small x by extending the measurement done at HERA [11]. Closely related experiments can be also be carried out at the Tevatron. It is also important to measure baryon asymmetry for hyperon production in such experiments, since it is sensitive to the mechanisms under discussion.
- As the gluonic mechanisms generating BN are flavor independent one should see an excess of BN in every baryonic channel. Also this mechanism produces a much larger yield of strange and multi- strange baryons in relativistic heavy ion collisions than comes from conventional quark-diquark string models.
- A new mechanism for $\bar{J}J$ string junction pair production via color-decuplet gluonic (or string-junction) exchange is suggested in [12]. It naturally leads to long range rapidity correlations between produced baryons and antibaryons. This should be tested at the Tevatron collider.

- We expect the gluonic double step mechanism of BN stopping to dominate in the SPS-RHIC energy range for the central collisions of very heavy ions. In this case it should lead to about three times more stopped BN than is predicted by preasymptotic mechanisms [21, 23].
- The mechanism of string junction flow for BN stopping leads to enhanced hyperon production, more for the asymptotic than preasymptotic mechanisms. Since both mechanisms involve distraction of the projectile diquark, the transverse momenta of produced particles should be increased in such events. Both effects are enhanced in central collision of heavy ions.

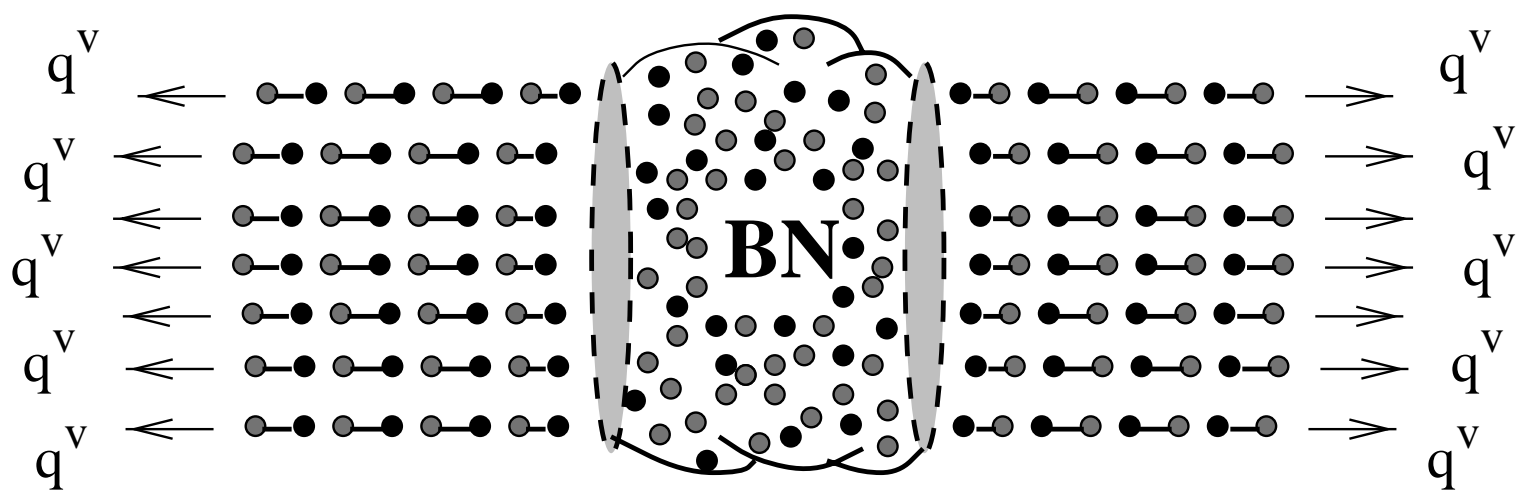
Acknowledgments: we are thankful to A. Rostovtsev for informing us about data [15].

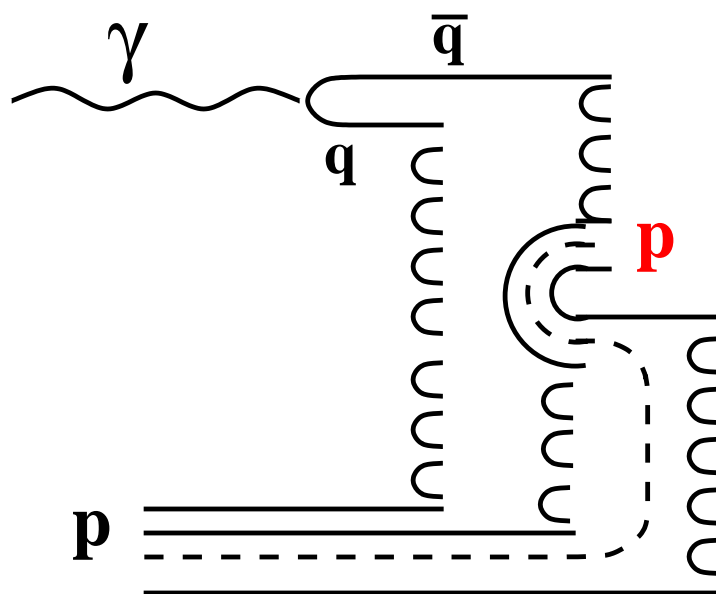
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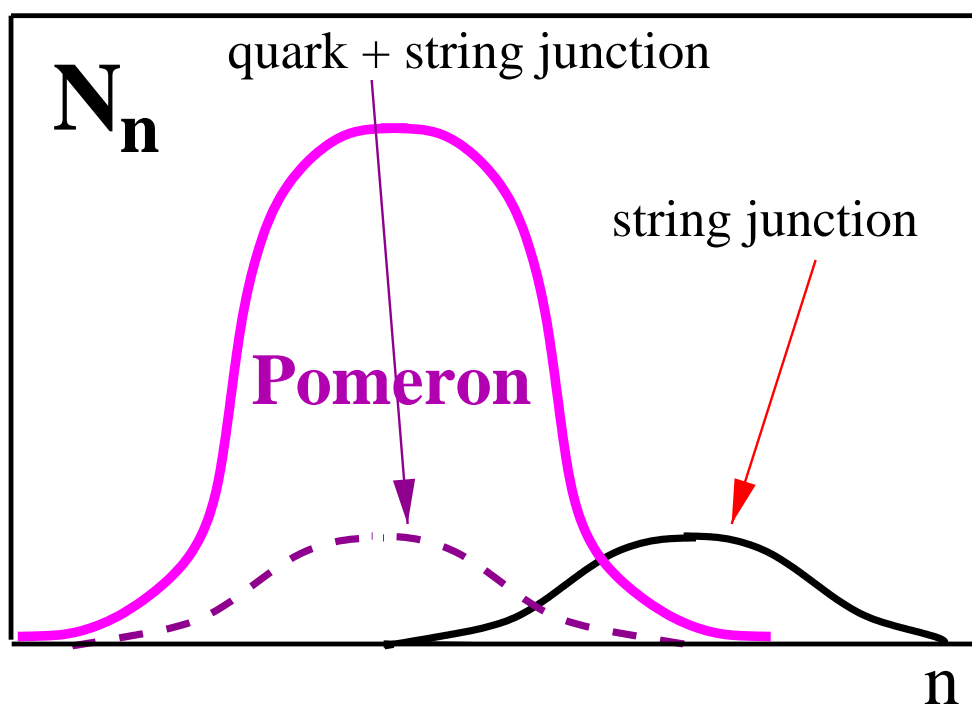
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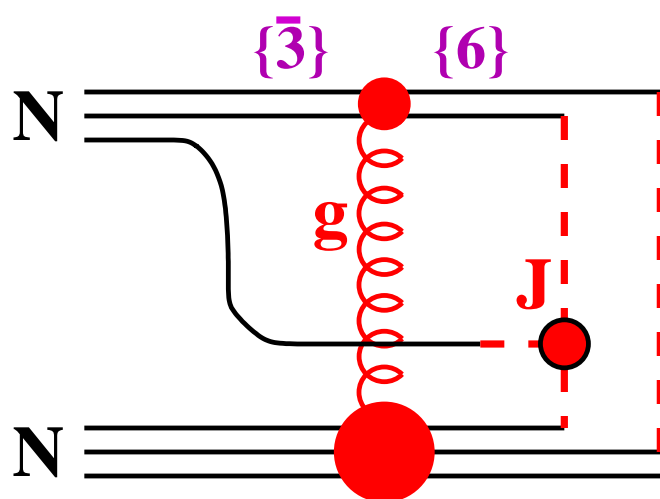
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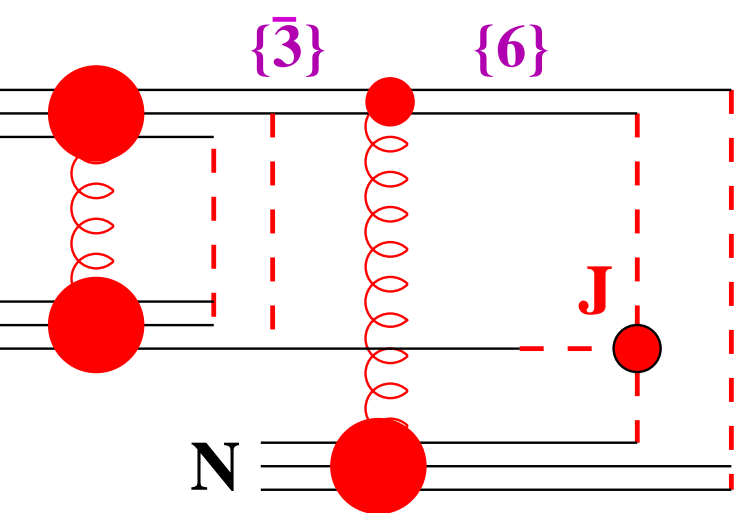
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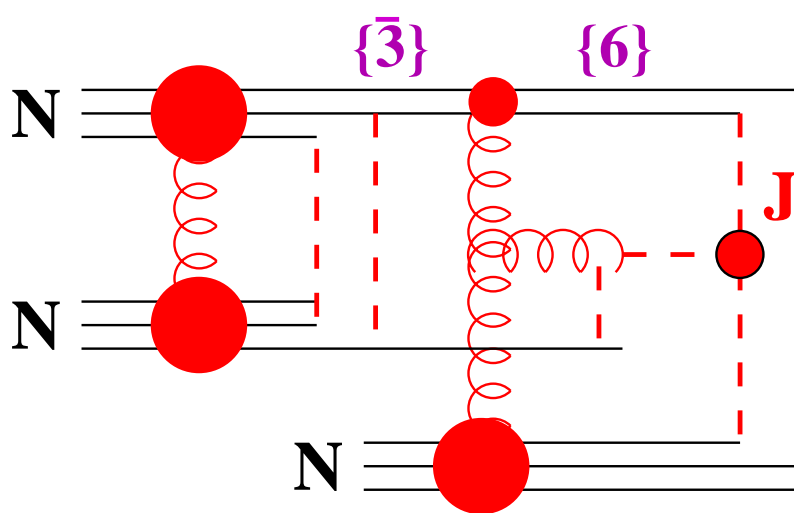








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